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On the Form of the Intraventricular and Aortic Pressure Curves obtained by a new Method

by

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(With pl. XX and one cut.)

It is not our purpose in the present paper to enter into a discussion of the various forms of endocardial pressure curves obtained by different observers with various methods of registration, nor do we intend to review the history of the question; but shall content ourselves with referring readers to Tigerstedt's account on pages 82 to 108 of his „Lehrbuch des Kreislaufs" (1893).

In view of the difference of opinion as to the true form of the intraventricular pressure curve, we thought it advisable to attempt the registration of the curve by a totally different method and this as simple a one as possible; accordingly, we devised the manometer, a short account of which was published in the Guy's Hospital Reports, 1892, p. 307. In this instrument, we photograph the changes of volume of a small air-space at the end of a capillary glass tube, connected directly with the cavity (left ventricle or aorta), the variations of pressure within which we desire to investigate. To do this, a piece of thick-walled glass tubing about 1 cm in diameter is drawn out at one end in the blow-pipe flame to a fine capillary, the dimensions of which, in the particular instrument we made use of, will be

found below. This is connected by narrow lead tubing to a threeway stopcock, from which on the one hand a tube proceeds to a pressure-bottle, containing 25 % magnesium sulphate solution, and on the other to a short piece of lead tube, soldered to a brass nozzle, which fits into a brass stopcock at the end of the heart catheter. By this means, the capillary tube can be put into connection, either with the pressure bottle or with the heart cavity. To prepare the instrument for use, the point of the capillary being open, fluid is run in from the pressure-bottle, until a small air-space is left at the top, and the point is then sealed by a flame, so that the cavity is closed. The meniscus at the junction of the air and fluid is then focussed by a Zeiss A. microscope objective on to the surface of a photographic film attached to a rotating cylinder, a lime-light lantern being used as source of light. Between the microscope lens and the cylinder, there are interposed — 1st. a shutter for convenience of exposure; and, 2nd. a narrow vertical slit. The image of the slit being focussed on the film by a cylindrical lens, gives a very fine sharp line of light, broken by a dark band where the image of the meniscus falls. One boundary line of the band can be focussed quite sharply by means of the fine adjustment of the microscope. A tuningfork of 50 vibrations per sec. with a slip of paper projecting from one limb across the slit, serves to register the time. The films found most convenient were Edwards' Isochromatic Instantaneous and were developed by Eikonogen.

The dimensions of the air-space were the following:

Length . . . . . . 3·8 mm
Diameter . . . . . . 0·3 mm

therefore volume = 0·268 cub. mm.

It is well at the outset to state that we do not lay any stress on absolute measurements of pressure made with this instrument, for two reasons:

1st. It is impossible to obtain accurate measurements of the dimensions of the air-space, and the capillary is probably very slightly conical in form, and:

2ndly. We have no means of knowing how far the compression of the air takes place adiabatically. If the pressure-bottle is quickly

placed in connection with the capillary by turning the stopcock, the air is compressed, but photographs taken of this seem to show that the heat formed escapes as rapidly as it is produced, for the volume of the air-space does not further diminish under continued exposure to the same pressure, as it would do if it had been heated, and moreover the rate of compression is probably not sufficiently rapid for it to be adiabatic.

Let us now see how far the instrument fulfils other conditions of a good manometer.

I. *As to mass moved.* It is obvious that a great advantage is gained by the abolition of levers etc., for recording the movement; and, besides the diminution of mass, the photographic method has the further advantage of giving curves whose ordinates are straight lines instead of arcs of circles, as in all cases where levers moving around a centre are employed. The only mass moved is the volume of fluid forced into and out of the capillary; this we have measured, and find that, for 100 mm mercury increase of pressure, there is a volume of fluid moved equal to 0·0335 cub. mm. In this respect it compares very favourably even with Hürthle's small "Gummimanometer", the corresponding volume of fluid in which is equal to 90 cub. mm.[1])

II. *As to Rapidity of Movement, or Inertia.* The most rapid rate of change of pressure we were able to produce was one of 4750 mm Hg. per second, and to this our instrument responded accurately, although with a few vibrations before coming to rest. Hürthle's instrument, undamped, could move at a rate of 10 000 mm Hg. per second. In this respect therefore, we can only say that our instrument responds to the most rapid rate at which we have tested it.

III. *As to Mobility.* In respect of latent period, we have made no measurements, but that the instrument can respond to rapid changes of pressure is shown by the fact that the number of vibrations, produced in the instrument itself by very suddenly turning on the pressure-bottle, amounted to 63 per second.

IV. *As to Aperiodicity.* When the tap connecting the manometer

[1]) Pflüger's Archiv. XLIII, p. 409.

to the pressure-bottle is turned at such a rate that the pressure in the manometer changes at the rate of 1100 mm of mercury per second [1]), the meniscus takes up its final position without vibrations, as shown by the photograph Fig. 1. plate XX. (The lower angle is the one to be observed.) When the rate of change of pressure exceeds this, there are a few rapid vibrations (63 per second), before the meniscus comes to rest. Measurements of the most rapid changes in the intraventricular curve (the ascending part) show that in the cases observed by us, it never exceeded 1000 mm Hg. per second, and this is within the capability of the instrument to respond to without vibrations. An important point is that, in the capillary manometer, this aperiodicity is obtained without any additional damping, as in Hürthle's and von Frey's instruments, although the former instrument can be at any time damped to any degree once found to be adequate by means of the graduated scale to the stopcock, and in practice shows itself to be a very convenient and accurate instrument.

A final advantage the capillary manometer possesses as an accurate recorder of pressure curves is that the unavoidable friction of the tracing point on the smoked paper is absent; anyone, who has worked with any of the manometers writing on smoked paper, knows how very little friction is sufficient to obliterate all the secondary waves on the curve.

Our object in describing this capillary manometer is to show that it is an instrument giving a truer reproduction of the intraventricular variations of pressure than any other equally simple one, and therefore curves obtained by it may serve as standards with which to compare those obtained by any other form of manometer, and to accept or reject them accordingly. Our method is not one capable of general use, because of the complications of the photographic recording method, but it seemed to us worth doing on account of the truth of the records so obtained.

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[1]) Of course this does not mean that the pressure ever reached this amount, the pressure actually used (equal to the height of the pressure-bottle above the manometer) was 95 mm Hg. and, in the case mentioned, this was reached in 0·08 secs.

Method of Experiment. Large dogs only were used; these were anaesthetized with a hypodermic injection of morphia, half to one hour before the experiment, and during the latter by the inhalation of a small amount of A. C. E. mixture, in addition. The left carotid artery was dissected out in the neck, and the heart catheter, consisting of a piece of German silver catheter tube open at the cardiac end and provided with a stopcock at the other end, which fitted tightly the nozzle of the lead tube of the manometer, was inserted into the central end, and gently pushed down between the semilunar valves into the left ventricle. After a few trials, it is easy to do this, and the sudden change of the beats of the upper end of the tube indicates when the cavity of the ventricle is reached. There is thus an open communication between the manometer and the heart cavity. Clotting very rarely occurs when the catheter has been previously completely filled by 25 % Magnesium sulphate solution, no doubt because such a very minute quantity of blood enters the tube at each beat. The vagi were usually cut and the peripheral end of one of them prepared for excitation.

The Intraventricular Pressure Curve.

The general form of the curve is as described originally by Chauveau and Marey[1]) and confirmed by Fick[2]), Frédéricq[3]), and Hürthle[4]), and consists of:

1. A very steep ascending limb;
2. A plateau nearly parallel to the abscissa, or ascending or descending, and having upon it three waves more or less wellmarked; and
3. A very steep descending limb. (Figs. 2, 3, 4, 5, and 6. Plate XX.)

The auricular beat is generally shown by a slight elevation at the foot of the ascending limb, (seen best in Figs. 4 and 5, under

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1) Gazette méd. de Paris. 1861, p. 320.
2) Pflüger's Archiv. XXX, p. 600.
3) Travaux du laboratoire. II, pp 73, 74. 1888.
4) Pflüger's Archiv. XLIX, pp. 29 et seq. 1891.

vagus excitation). The rate of increase of pressure during the quick ascent is, as already mentioned, 1000 mm Hg. per second and in our curves (Fig. 2) it reached the amount of 87 mm Hg., that is, supposing the heat produced during the compression of the air to have been dissipated as fast as formed. If the compression were adiabatic, the amount of pressure needed to produce the observed deflection can be calculated by the formula:

$$\frac{(V)}{(V')}^{K} = \frac{P'}{P}$$

where V is the original volume of the air under the original pressure P, i. e., in our experiment, the atmospheric pressure, and V' is the volume under the pressure P', that is, the intraventricular pressure, plus the atmospheric pressure, and K is the ratio of the two specific heats of a gas, that is, 1·4. When calculated out by this formula, the maximum pressure produced in the left ventricle amounts to 128 mm Hg. as against 87 mm Hg. The real value is probably somewhere between these two, but as said above, we lay no stress upon absolute measurements of pressure based upon our curves.

The three waves constituting the plateau vary considerably in relative height. Sometimes the first is the highest, as in Figs. 5 and 6, and at other times, the second is higher than the first, as in Figs. 2, 3 and 4. When the heart is beating quickly, the third wave is not very distinct, but is quite marked in Fig. 6, and is always to be seen. It shows itself better when the heart is slowed by moderate excitation of the vagus, as in Fig. 4. We are not prepared to give an interpretation of these waves, nor do we think that a sufficient one has been as yet suggested. Roy and Adami [1]) consider the second wave to be due to contraction of the papillary muscles. This much we can say positively, that the three waves are not of instrumental origin, and this for several reasons. In the first place, we have shown our instrument to be aperiodic for such rates of change as occur in the heart-beats investigated by us. In the second place, if the waves were due to vibrations set up in the column of fluid in the tube, the second

[1]) The Practitioner. 1890. I pp. 88—94.

wave would be *less* than the first, whereas it is usually *greater* (i. e., the curve is anacrotic). In the third place, if these were instrumental vibrations, their period would be $^1/_{63}$ of a second, as shown above, where as it is much longer, about $^4/_{50}$ of a second, in fact; and the interval between the first and second is moreover considerably less than that between the second and third. This last point is shewn best in Fig. 6, where the drum was moving at a slightly greater speed than in the other figures; unfortunately, the tuning fork was not in position, so that we must give the measurements in distance, the interval between the first and second waves being 3 mm, and that between the second and third being 4 mm.

In Fig. 4 (vagus excitation) and Fig. 6, there is seen the wave on the descending limb, first noticed by Chauveau and Marey, and not obtained in the dog until recently (by Frédéricq and Hürthle with improved methods of registration).

When the heart is beating slowly (Figs. 4 and 5), there is a well-marked negative pressure in the ventricle at the commencement of diastole. In amount this is about 23 mm Hg.

The wave following the negative pressure in Fig. 4 is no doubt an auricular beat, since it bisects the interval between the undoubted auricular beats preceding the two ventricular beats. In this case the ventricle was only beating in sequence to each alternate auricular contraction, as so often happens in vagus excitation.

One point remains to be mentioned. Von Frey's explanation of the origin of the plateau, viz., that the sound was inserted too far into the ventricular cavity and was obstructed by the ventricular walls before the systole was completed[1]), certainly does not hold good for our experiments, since our catheter tube was only passed just beyond the aortic valves and its withdrawal by only about $^1/_2$ an inch was sufficient to convert the ventricular curve into an aortic one.

The Aortic Pressure Curve.

The aortic, like the intraventricular pressure curve, is sometimes anacrotic (Figs. 7—10. Plate XX), but it always shows the three

[1]) Frey und Krehl, Arch. für Anat. und Physiol., Physiol. Abteilung. 1890. pp. 37—42.

waves of the ventricular plateau followed by the dicrotic notch, and occasionally (Fig. 8) the three are very sharply marked. There is one wave distinctly and invariably present immediately following the dicrotic notch; this is usually followed by another less distinct, and sometimes there are one or more small following undulations. A point of interest is the slight depression, seen best in the two first beats of Fig. 8, which occurs immediately before the sharp upstroke.

Relation of the Intraventricular to the Aortic Pressure Curves.

If we compare the aortic and intraventricular pressure curves taken immediately following one another, so that the heart was beating at the same rate and under similar conditions as regards arterial pressure, as, for instance, Figs. 2 and 8, by superposing them one upon the other (as Frédéricq has done[1]) we see how close is the agreement between the first part of the aortic curve and the upper part of the ventricular curve. The figure at the end of this paper was obtained in the following way. Images of curves Figs. 2 and 8 were projected by means of a lantern on to a piece of paper, at such a distance from the lantern lens that the magnification was about twice the natural size, and their outlines were followed by a pencil. In the Figure, the aortic curve is at the top and the ventricular one at the bottom; the middle curve was obtained by first tracing a ventricular curve like the bottom one, and then projecting on to it an aortic curve, like the top one, taking care of course that the systolic upstrokes of the two curves coincided. We see now that the first two waves of the ventricular plateau coincide exactly with the first two aortic waves, and that the third corresponds in position, but is rather higher in the aortic curve. The descent of the two curves corresponds for a certain distance, i. e., to the point where Hürthle and Frédéricq place the closure of the aortic valves; from this point the ventricular curve continues its descent, while the aortic curve is raised again by the arrival of the dicrotic wave. The point where

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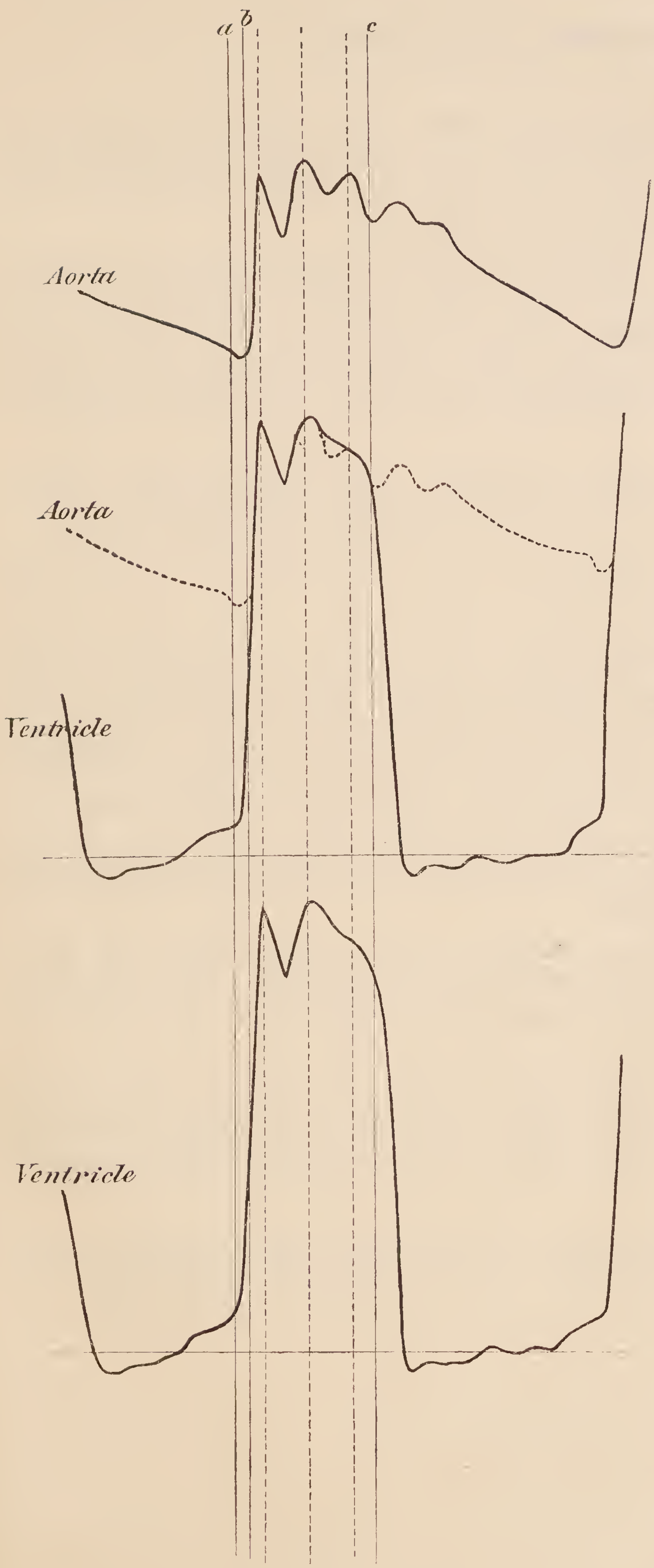
[1]) Éléments de Physiologie. 3rd. Edit. 1893, and in Centralblatt f. Physiologie. 1893, p. 42.



the two curves depart from each other is marked in the Figure by the line *c*. The interval between the two vertical lines, *a* and *b*, is the time taken by the ventricular pressure to reach that of the aortic and to open the semilunar valves (the "Anspannungszeit" of Gad). The three vertical dotted lines of the figure mark the summits of the three waves of the ventricular plateau.

In conclusion, the points on which we would lay most stress are, that the true form of the normal intraventricular pressure curve is that of a plateau with three summits, as originally described by Chauveau and Marey; and that a blood-pressure manometer approaches accuracy the more nearly, the more perfectly it gives this form of curve.

Description of plate XX.

All Figures to be read from left to right. Time tracing (when present) in fiftieths of a second. In all, (except Fig. 10), the lower edge of the meniscus was focussed, so that the curve to be read is formed by the line of junction of the lowest white area with the middle grey or black area.

Fig. 1. Test of instrument. Deflection caused by suddenly diminishing pressure from 95 mm of mercury to zero. Shows absence of vibrations with a rate of alternation of pressure at least as steep as that of the intraventricular pressure. The faint vertical lines, (caused by slight regular variations of velocity of the photographic film), serve as convenient ordinates to measure from.

Fig. 2. Intraventricular pressure of left ventricle. Heart beating quickly. Plateau with three waves on the top, second, and third waves partially fused.

Fig. 3. A similar curve from another dog, heart beating rather more slowly, second wave higher than the first.

Figs. 4 and 5. Intraventricular pressure of left ventricle. Vagus excited. Shows auricular beat, the three waves on the summit of the plateau, the wave on the descent, and considerable negative pressure following the ventricular beat. The beat after the negative pressure in Fig. 4 is apparently an auricular beat not followed by a ventricular beat, owing to the vagus excitation. In Fig. 5, there are also some isolated auricular beats.

Fig. 6. A similar curve from another dog. Heart beating slowly from morphia. Shows very distinctly the three waves on the summit of the plateau and the notch on the descent.

Figs. 7, 8 and 9. Various forms of katacrotic, aortic pressure curves. In Fig. 7, vagus excited. All show three waves (corresponding to the three waves on the plateau of the ventricualr curve) preceding the dicrotic notch and two waves following it.

Fig. 10. An anacrotic aortic pressure curve. In this case the top of the meniscus was focussed, so that the curve to be read is the junction of the grey area with the white strip between it and the uppermost lighter grey area. (An unusual form.)

Note. Figs. 7 and 8 come from the same dog as Fig. 2, and Fig. 9 from the same dog as Figs. 3, 4 and 5, Figs. 6 and 10 come from two other dogs.

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